Farming System 3 (2025) 100139

Contents lists available at ScienceDirect

Farming System

journal homepage: www.journals.elsevier.com/farming-system

How has scientific literature addressed crop planning at farm level: A bibliometric-qualitative review

Aniket Deo [a,b,*], Namita Sawant [b], Amit Arora [b], Subhankar Karmakar [c,d]

[a] Borlaug Institute for South Asia (BISA), International Maize and Wheat Improvement Centre (CIMMYT), New Delhi, 1100012, India
[b] Center for Technology Alternatives for Rural Areas, Indian Institute of Technology Bombay, Powai, Mumbai, 400076, India
[c] Environmental Sciences and Engineering, Indian Institute of Technology Bombay, Powai, Mumbai, 400076, India
[d] Interdisciplinary Programme in Climate Studies, Indian Institute of Technology Bombay, Mumbai 400076, India

ARTICLE INFO

Keywords:
Farming system
Decision making
Systematic literature review
Cropping system
Bibliometric analysis

ABSTRACT

Crop planning (CP), being the core of farm management and decision-making, remains significant as the selection and allocation of appropriate crops determine the economics and sustainability of farming system. A systematic literature review was conducted to obtain a structural overview and consolidate the knowledge from CP literature, given the dearth of review articles in this domain.

The methodology included systematic selection of literature in phases and mixed-method systematic review process consisting of bibliometric analysis and qualitative review. This enabled an understanding the main characteristics of CP literature and answer how CP has been addressed at farm level.

1516 publications were selected in first phase after which 652 were screened using bibliometric analysis software, VOSviewer and CiteSpace, in second phase to identify research hotspots and recent trends. Optimization, irrigation, sustainability, adaptation were certain hotspots, while a shift in research trend was observed from decision support, crop allocation and bioenergy to climate change, water resources and big data. Last phase focussed on qualitative review of 31 publications on farm. Three broad themes of articles emerged namely "farmer's decision-making", "soil-water-agroecology" and "merits of innovative technologies". The study proposed several recommendations for small farming systems which were largely ignored in literature. These include factorial design for crop combinations, choices in options, estimation of crop diversity index and relative time-dispersion in yields. The current review produced a macroscopic overview of accumulated knowledge on CP and provided future directions to harness the unexplored potential in this field.

1. Introduction

Rising world population, modern food habits, food losses and wastages have necessitated growth in agricultural production (Pruntseva et al., 2021). To meet the food demand in 2050, the agricultural production should increase by around 47% (Sands et al., 2023). However, climate change, biodiversity loss and depleting agricultural resources pose significant challenges to achieving these goals. Moreover, shocks in farm income caused due to fluctuating market rates and uncertain yields are compelling many farmers to quit agriculture and switch to stable income sources especially in developing countries like India (Chand, 2017). This is an alarming situation for food, nutrition and livelihood security globally.

Efforts by agriculture researchers, scientists and institutional bodies emphasize on the need for evolving existing cropping systems into more robust, climate resilient and profitable systems. Strengthening the adaptive capacity of the cropping systems is crucial (Dury et al., 2012). These efforts highlight the importance of efficient farm management and decision making. Considering complex interrelation between different elements of the farming systems, crop planning remains at the core of farm management (Nevo et al., 1994). Selecting appropriate crops based on local agroecology and resource capacities, while ensuring commercial viability, determines the sustainability and profitability of farming systems (Gomaa et al., 2011).

In the current era, crop planning has become essential as farmers must continuously adjust their cropping systems to the uncertain external factors such as climate change and resource availability (Dury et al., 2012). Institutional changes, household dynamics, shift to mixed

* Corresponding author. Borlaug Institute for South Asia (BISA), International Maize and Wheat Improvement Centre (CIMMYT), New Delhi, 1100012, India.
E-mail address: a.deo@cgiar.org (A. Deo).

https://doi.org/10.1016/j.farsys.2025.100139
Received 6 August 2024; Received in revised form 18 January 2025; Accepted 18 January 2025
Available online 20 January 2025

cropping, uncertainty in market rates, resource scarcity and degradation necessitate dynamic and informed changes in cropping system. However, the permutation of scenarios, complex inter-linkages and uncertainty associated with farming system makes crop planning a challenging problem (Itoh et al., 2003). As a result, crop planning research remains important and relevant in supporting farmer's decisions, analysing alternative scenarios and evaluating impacts of cropping systems on agro-ecology, environment and regional economy.

Crop planning problem has been studied extensively as an analytical problem and explored using model-based explorations, due to the advantages of mathematical modelling over traditional empirical approaches. Previous reviews, such as Dury et al. (2012), have described when and how cropping plan selections have been modelled. Rajni et al. (2018) provided an overview of optimization techniques used in crop planning, while Gomaa et al. (2011) focused on crop planning and water management as optimization problem in their review. The primary aim of previous reviews in crop planning domain has been to highlight the purpose, tools and techniques of crop planning. Overtime, crop planning research has extended beyond agronomy, with contributions from mathematicians, computer scientists, environmentalists, geologists, and hydrologists. The quantum of literature available on crop planning research has grown substantially, making it difficult for practitioners and researchers to study a comprehensive and structured overview of relevant literature (Rodrigues et al., 2014).

A bibliometric analysis could provide a macroscopic overview of research growth, trends, emerging fields and multi-disciplinary directions in crop planning. However, so far, bibliometric analysis is absent in crop planning literature specifically. Our study aims to fill this gap by focusing on farm-scale crop planning-a level that has received limited attention compared to larger-scale analyses (Dury et al., 2012).

Farm-scale research is particularly important because farmers are the primary stakeholders and beneficiaries of crop planning studies. To expect agriculture to meet the demands of the population while also protect the natural resources, we must fulfil the needs of farmers who manage the lands (Jones et al., 1997). Besides, crop planning research at farm-scale has tremendous scope since conditions at farm scale are highly heterogeneous and require farm-specific solutions. With an estimated 570 million farmers worldwide (Lowder et al., 2016), each managing unique farm conditions, it highlights that 570 million different farm conditions exist, making farm-scale research highly valuable. Moreover, insights from farm-scale studies benefit not only farmers but also policymakers and private and public sector actors. Understanding farmer's decision-making processes, production potential, and resource use efficiency at the farm level can inform regional land and resource use planning at larger scales. (Kamilaris et al., 2017).

Despite the importance of farm-scale research, no existing reviews or surveys consolidate studies on crop planning at this level. To address this gap, the objective of this study is to conduct a systematic literature review (SLR) and answer the research question: How has the crop planning problem been addressed at the farm level? Our study provides a structured synthesis of the literature, uncovering research hotspots, growing trends, and themes in farm-scale crop planning studies while offering directions for future research.

2. Methodology

SLR has an advantage over the traditional review process in terms of reducing researcher's bias (Petticrew and Roberts, 2008), as it is done using structured protocols which enables the researcher to extract, include/exclude, analyse and report the findings in a transparent manner. This ensures trustworthiness in the conducted research and legitimacy in claims made. The below sub-sections describe the process in this SLR study.

2.1. Identification of literature

Two popular databases- Web of Science (WoS) and Scopus were used for identifying appropriate scientific literature related to crop planning. These databases have significant coverage and cover multiple disciplines for bibliometric and scientometric analysis (Mongeon and Paul-Hus, 2016). The search platforms provide simple exploration of literature using field tags, Boolean operators and filters that help generate efficient search queries. A PRISMA based procedure was followed to report the stages of literature search and screening of results. The flowchart in Fig. 1 illustrates the three-step protocol of PRISMA procedure: identification, screening, and inclusion. The queries and screening criteria are discussed next.

2.1.1. Search queries

At first, pilot searches were carried out using “crop planning” as the sole search query. Further to improve the coverage, items such as “cultivation plan”, “cropping plan”, “cultivation planning”, “crop selection”, “crop allocation” and “crop combination” were added in the search query as they closely resembled these terminologies. A Boolean operator “OR” was applied to develop a search string using the above items. A field tag TS (topic) in WoS and TITLE-ABS-KEY (title + abstract + keyword) in Scopus identified 651 and 1399 publications in English respectively. Out of the total 2050 publications, 534 were found to be duplicates (as they were retrieved from both Scopus and WoS) and were removed. Finally, in the first phase of literature scrutiny, 1516 publications were segregated.

2.1.2. Inclusion and exclusion criteria

Publications shortlisted in the first phase were further filtered using a few criteria. Since the objective of this study was to understand how crop planning problem has been addressed therefore, publications which did not contain a method, tool or framework to address crop planning were excluded. For these items containing the following criteria were used: “decision-support”, “optimization”, “decision-making”, “models”, “modelling”, “decision-aid”, “programming”, “optimal”, “expert”, “software” and “smart farming” were used, essentially because, these items are used to make the tools for assessment and solving crop planning problems. The items above were combined with “OR” operator and, included in the previous search query with “AND” operator. This process filtered 329 publications in WoS and 584 publications in Scopus with, 261 duplicates. Eventually, a total of 652 publications were screened in the second phase, eliminating 864 publications from first phase.

Since, this study focussed on crop planning problem at farm level, an additional criteria concerning scale of study was included in the third phase. Items such as “farm-level”, “farm-scale”, “field scale”, “field level”, “micro-scale” and “micro-level” were combined with “OR” and included with “AND” in the search query of the second phase. This reduced the search results to 24 and 30 in WoS and Scopus respectively. Thus, a total of 31 publications were shortlisted after eliminating 23 duplicates.

2.2. Review process

For the review, a “mixed method systematic review” process termed by (Harden and Thomas, 2010) was employed in this study. This method involved quantitative bibliometric analysis and a qualitative review of the shortlisted literature. The literature search which was conducted in three phases used different criteria and process. In the first (n = 1516) and second (n = 652) phase of selections, bibliometrics was used, while qualitative review was conducted for third phase selections (n = 31). Table 1 illustrates the procedure used for mixed method systematic review in this study.

Bibliometrics is a popular field which provides quantitative and statistical methods to measure literature indices that contribute to scientific

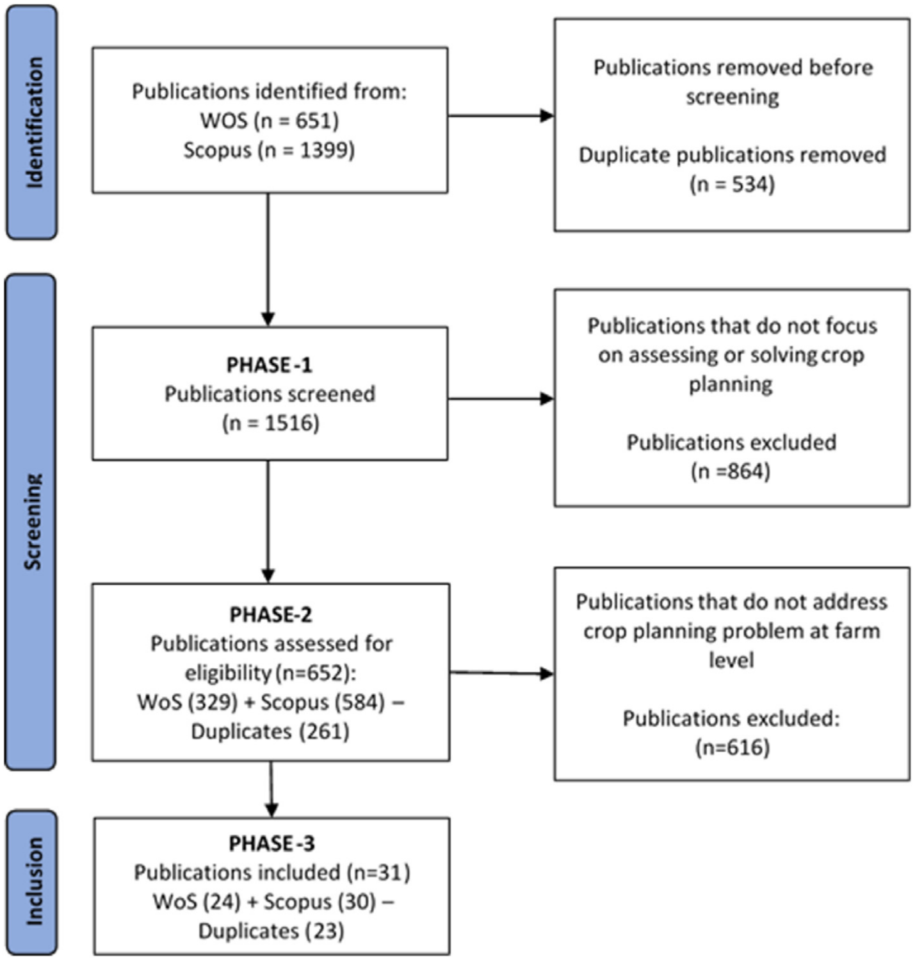

Fig. 1. PRISMA flowchart with selection and exclusion records.

Table 1
Mixed method systematic review. Table inspired from (Oraee et al., 2017).

Phases	Evaluation	Literature dataset	Method of analysis
Phase-1	Crop planning literature	n=1516	Bibliometric (MS Excel)
Phase-2	Research associated with assessment or solving crop planning problem	n=652	Bibliometric (VOS viewer and Citespace)
Phase-3	Research focussed at farm level	n=31	Qualitative (manual)

and academic environment which are characterized by measuring keywords, citations, journals, researchers and their trends (Araújo, 2006). To take account for growth trend in quantity and, quality of research in crop planning domain, the publication year and citations of the articles scrutinized in the first phase were analysed using MS Excel. With the advent of tools for computerized data treatments in bibliometrics, the extraction and manipulation of large volume of publication data was possible (Ellegaard and Wallin, 2015). For this study, in the second phase of bibliometric analysis, a co-keyword network analysis and keyword burst detection analysis were used using VOS viewer (van Eck and Waltman, 2010) and Citespace (Chen, 2006). Co-keyword network analysis is the relationship among the keywords in case of co-occurrences and, keyword burst detection analysis is identifying keywords which receive attention for a particular time. This analysis provided the research hotspots and emerging trends in crop planning domain. The method of analysis for each phase of selection is mentioned in Table 1.

For qualitative review, all 31 publications selected in third phase were thoroughly studied. The purpose was to interpret the concepts and theories outlined in the publications. The objectives, methods, focussed parameters, important observations and results from these publications were identified. The intention was to provide a qualitative synthesis of publications when for crop planning at farm level. Further, these publications were categorised into themes to depict the essence of their work.

3. Results

The review methodology yielded evidence of evolution of crop planning literature and how it was addressed at farm level. This section presents the main results obtained from bibliometric analysis and qualitative review.

3.1. Bibliometric analysis

Bibliometric analysis was mainly used to understand the evolution of crop planning literature. Using data from publication records and data processing tools (VOS viewer and Citespace), the observations from bibliometric analysis are presented in the subsequent sections.

3.1.1. Publication output and growth trend

The number of publications in a particular field depicts the development pattern of scientific research, while the number of citations describes the quality of the publications. In this study, we recorded the volume of publications and sum of citations per year which are presented chronologically in Fig. 2.

The progression in publications and sum of citations per year in Fig. 2 illustrated a growing trend in crop planning research from 2000 to 2020. In the collected database (n = 1517), the earliest publications were from 1967, however, to understand the growth trend, we considered publications from the last two decades. Therefore, n = 349 articles published before 2000 were not considered in Fig. 2. Following the trend in publication per year (exponential trend line with $R^2 = 0.946$), it could be predicted that the number of studies in crop planning research will increase in the future. Publication output, citations and growth trend in this field can partly be justified by the need for research to address various uncertainties in crop planning. The growth trends also suggest the growing interest of researchers in this field, given the rising vulnerabilities of current cropping systems. The publications belonged to the domain of agricultural and biological sciences, environmental sciences, earth and planetary sciences, engineering and computer sciences suggesting the wide interest of researchers across various discipline.

3.1.2. Co-keywords and keywords citation bursts analysis

Keywords are chosen to reflect the essence of the articles and enables the indexers and search engines to find relevant papers. The bibliometric data showed that 3722 keywords were used in the collected database. A keyword co-occurrence analysis was conducted using VOSviewer software which showcased the relationships among the keywords and research hotspots in crop planning domain. The co-occurrence emerged from citation of articles as references, in other articles. Fig. 3 presents a co-keyword network based on occurrences and average publication per year when, co-occurrence threshold of the keywords was set at 5 following which 111 items were visualized.

The size of circles in Fig. 3a represents the occurrence of the keywords. The larger the circle, more times a keyword has been co-listed in crop planning publications. Other than obvious keywords such as crop planning, agriculture and crop selection, important terms such as optimization, irrigation, sustainability, horticulture, adaptation etc. repeatedly appeared and highlighted the research hotspots in crop planning research. The links between two keywords is represented by curved lines in Fig. 3a and bold lines means stronger link strength. Link strength is defined as the number of times, two keywords have occurred together in publications. The colours of circles in Fig. 3a depict distinct clusters, such that keywords having same colour belonged to a particular cluster. Apparently, the clusters represent a sub-field or topic in crop planning research, however several keywords were mislaid in clusters. Therefore, the detailed description of clusters was not found useful and not reported in this study.

Fig. 3b shows the time-varying keyword occurrence from 2010 (dark purple) to 2016 (yellow) time scale. Keywords such as sustainability, climate change, precision agriculture, big data, machine learning have a more recent average publication year. Keyword visualization in Fig. 3b suggests the recent trends and the areas in which crop planning research is progressing. A network diagram, such as Fig. 3 and b, contains several linkages and occurrence dependent visualization which might be confusing. Therefore, based on occurrences, top 10 keywords are represented in a tabular form in Table 2. In Table 2, a link represents the co-occurrence of two keywords, and the total link strength indicates the total number of publications where two keywords appear together. Among the most frequently occurred keywords, recent research hotspots are concentrated on climate change and rainfall.

While keyword co-occurrence analysis provides a fair idea of recent trends in crop planning research, we conducted a keyword burst detection analysis to determine which keywords experienced a sharp increase in citations in a certain period. Burst detection provided insights into which keywords received particular attention with time. This was useful for observing the dynamics of crop planning research and explore the extensively researched directions. Using Citespace for burst detection analysis, top 9 keywords with strongest citation burst were identified. The results of burst detection analysis are illustrated in Fig. 4.

Fig. 4 highlights rapidly growing topics in this domain. The red lines

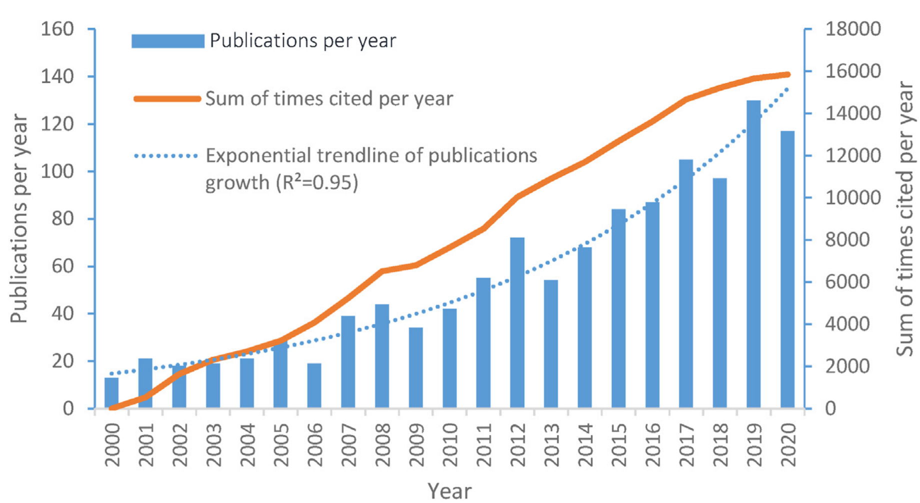

Fig. 2. Annual publications and citations of crop planning based on WoS and Scopus data base from 2000 to 2020 (n = 1168).

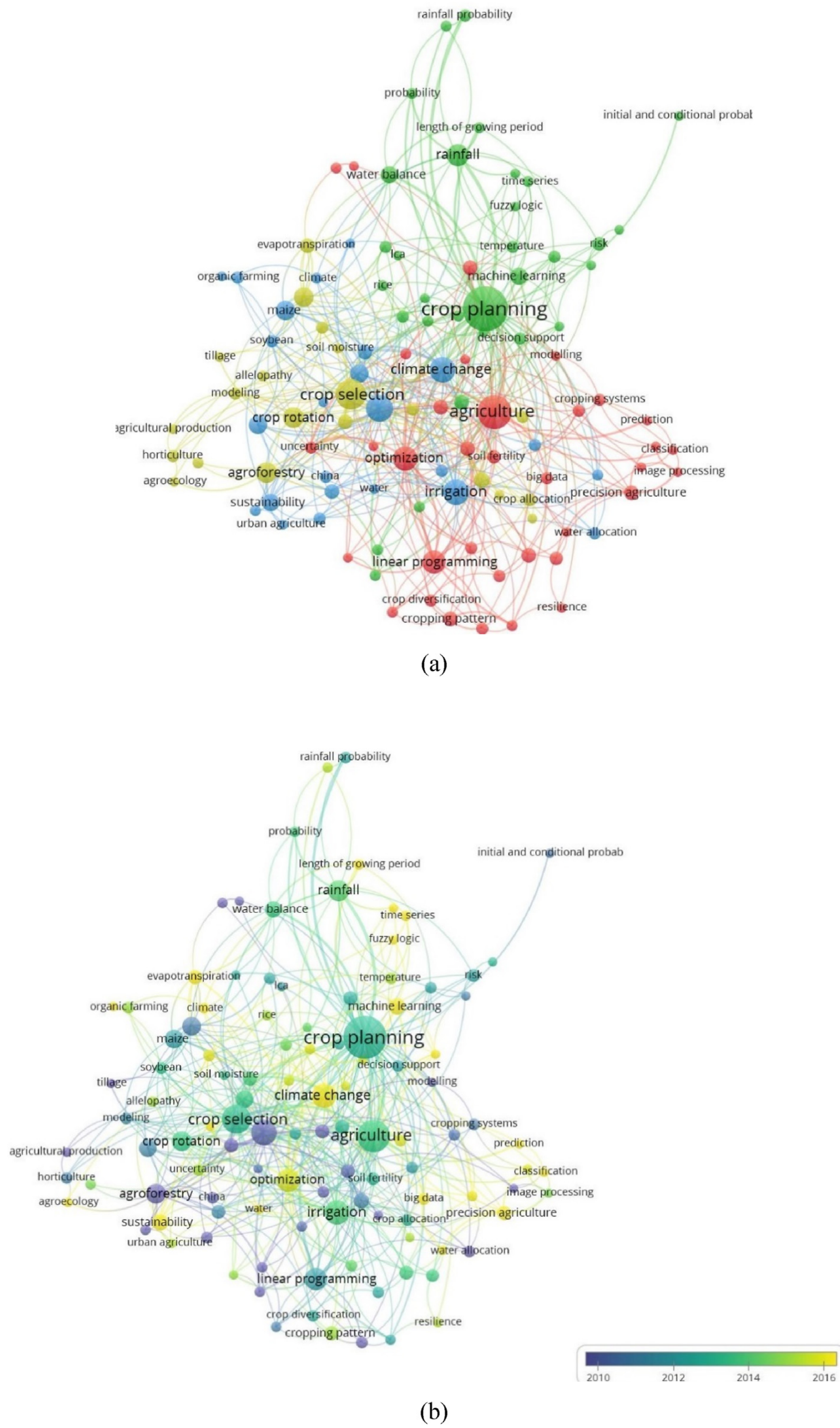

Fig. 3. Visualization of co-keyword network in crop planning research. Note: (a) co-keyword network visualization based on occurrences (b) co-keyword network visualization based on occurrences and average publication year per score.

in Fig. 4 represent the time frame during which the burst occurred. Linear programming was the first keyword with a burst detected in the period of 2001–2005, while climate change exhibited the strongest burst ranging from 2015 to 2021. The changing dynamics of keyword bursts could be observed in Fig. 4. Over the years, a shift was observed from decision support, crop allocation and bioenergy to climate change, water resources, optimization and big data. There is ample literature emphasizing the dire need for research in the field of climate change to mitigate the vulnerabilities of cropping systems. This notion was supported with Fig. 4, as climate change had a burst till date. Similar, researchers have begun using state of the art technologies such as big data in agriculture (Sarker et al., 2020; Pahmeyer et al., 2021) as evident in Fig. 4 wherein big data exhibited a recent burst from 2018 to 2021.

Table 2
The link and total link strength of the top 10 occurrence keywords.

Keyword	Occurrences	Number of links	Total link strength	Average publication year
Crop planning	96	48	109	2013
Agriculture	56	34	71	2014
Crop selection	43	28	39	2013
Intercropping	34	25	34	2010
Climate change	32	23	28	2017
Irrigation	31	30	39	2013
Optimization	28	25	46	2015
Linear programming	25	13	26	2011
Rainfall	23	15	28	2017
Crop rotation	20	17	23	2013

Note: Average publication year represents the average year of publication of the articles linked to a specific keyword. It is calculated by averaging the publication years of articles associated with that keyword according to their relevance or occurrence in the dataset.

3.2. *Qualitative review*

The studies shortlisted for phase-3 were carefully reviewed to understand how they addressed crop planning problem at farm level. Fundamentally, the objective, methods, parameters/indicators and important results/observations of each study were identified (Table 3) and used for segregating these studies into themes. An overview of characteristics of studies considered for qualitative review in presented in a tabular from in Table 3. These studies belonged to diverse fields and creating themes based on disciplines would not have been useful for the readers given the interdisciplinary nature of crop planning problem. Therefore, to get an exclusive perspective, we segregated the studies into three broad themes namely farmer's decision making, soil water agroecology and merits of innovative tools-techniques which are coded FR, EN and MT respectively to simplify referencing these themes throughout the manuscript. The themes focussed on farmer as a decision maker, environmental aspects of crop planning and innovative tools used to address crop planning problem. Fig. 5 presents the distribution of studies according to themes. In several instances, the study had multiple components mentioned above and therefore belonged to more than one theme (Fig. 5). The description of themes, their relevance to crop planning at farm level and related studies are described in subsequent sections.

3.2.1. *Farmer's decision-making*

The performance of farming system largely depends on the decisions made by the farmer (McCown, 2002). The dynamics of decision-making in agriculture is relational and complex wherein the farmer considers multi-dimensional criteria while making a decision (Dury et al., 2010). These criteria encompass personal, economic, social, agronomic and cultural elements related to farming system (McConnell et al., 1997). The stages of farmer's decision-making generally involve setting up the cultivation objectives, acquiring and processing information, identifying and evaluating alternatives and choosing the best alternatives (Willock et al., 1999). While this process need not be followed linearly, but the stages suggests that the farmer has to explore/analyse large quantum of scenarios, information, alternatives and opportunities before making a decision. This makes farmer's decision-making a complex problem and farming a difficult business. Crop planning studies in this theme address farmer's decision making that could be further segregated into two sub-themes namely decision support systems (DSS) and decision-making process. These themes are described below.

3.2.1.1. *Decision support systems.* To address this issue, many researchers have developed mathematical modelling-based DSS that analyses various cultivation scenario and aids farmers in making appropriate decisions (Dury et al., 2012). In the shortlisted literature, DSS have been developed to inform farmers, governments and institutions on the potential impacts of agricultural policies. The study by Pahmeyer et al. (2021) in Germany was focussed on developing a DSS "Fruchtfolge" for crop rotation, wherein they proposed an adaptation strategy which could reduce the profit losses from 15% to 10% from revised fertigation regulation. Likewise, the DSS developed by (Galán-Martín et al., 2015) produced optimal cropping plans which reduced the adverse effects of "greening rules" under new European Union's Common Agricultural Policy. In the UK, a similar study was conducted by Alexander and Moran (2013), in which they attempted to understand the incomes on risk averse famers by cultivating perennial energy crops. The study by (Belhouchette et al., 2011) study in France was to assess the impact of policy on farm incomes as a result of the Nitrate Directive.

With extensive crop modelling studies, many DSS have been extended into bio-economic model. From an agronomic perspective, Bergez et al. (2014) used crop models to incorporate soil and plant process for designing innovative cropping systems. Forster (2002) designed farm level bio-economic simulation model to explore scenarios of tillage systems, crop selection, land size for improved farm economics. Similarly, a bio-economic model developed by Belhouchette et al. (2011) analysed different states of cropping systems with nitrate leaching, erosion and water consumption to study effects of Nitrate directive in Midi-Pyrenees region (France). The use of modelling and simulation techniques enables exploration of all practical scenarios hence is a convenient alternative to field level experimentations. González-Díaz et al. (2012) simulated various farm management scenarios to understand short and long-term weed population dynamics. Another crucial segment where DSS finds applications is in resource-constrained conditions in which the farmer

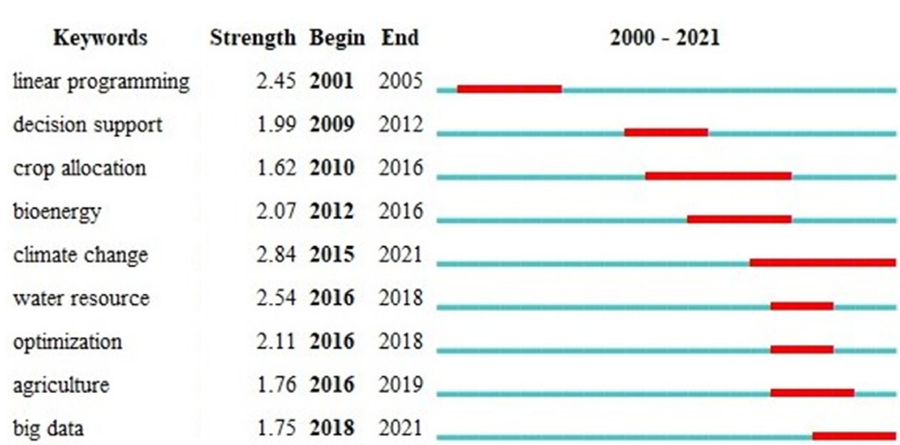

Fig. 4. Top 9 keywords with the strongest citation bursts in crop planning research.

Table 3
Characteristics of studies considered for qualitative review along with their proposed themes.

Authors	Objective	Technique	Parameters/Indicators considered	Important Observations/ Implementation	Theme
Pitovranov (1988)	To investigate effect of climate change on grain production and explore benefits of weather forecasting	Optimization	Climate change, crop yields, drought, irrigation	Case study (Saratov region): Drought promoted yield loss. Reallocation to drought-resistant crops were recommended. Weather forecast could improve scheduling	EN
Mohan and Arumugam (1994)	To develop expert system for crop selection		Climate, soil, topography, cultivation practices, available resources	The developed system was found to a valuable tool after evaluation from specialists	MT, FR
Hasler (1998)	To analyse environmental policy aimed at reducing nitrogen leaching at farm level and estimate cost-effectiveness	Modelling	Costs, nitrogen leaching, fertigation	Incentives from levies on commercial fertilizers were reduced fertilization and substitution with livestock manure.	EN
Mohan and Jothiprakash (1998)	To study and compare crop water requirement methods	Comparative analysis, FAO-penman, Duty-delta method	Crop water requirement	Duty-delta method underestimated the crop water requirement	MT, EN
Mira Da Silva et al. (2001)	To develop a decision support tool to improve planning and management of large irrigation scheme in Alentejo region, Portugal	Analysis of socio-economic and biophysical data	Crop yields, irrigation, farmer income	Specific actions and policies were designed for the studied area	EN
Forster (2002)	To study the effects of conservation tillage on the performance of Lake Erie basin farms	Farmer's data, statistical analysis, bio-economic simulation model	Tillage, rotation, farm size, crop selection	Tillage system, farm size and crop selection are jointly determined and could improve gains. Endogeneity in variables is observed	FR
Vavra and Colman (2003)	To analyse UK crop allocation at farm level	Supply response analysis	Crop allocation	Crop share changes were driven not only by economic variable but also many farms and enterprise specific and unrecorded variables.	FR
Wilson et al. (2003)	To study the impact of cereal prices on crop rotation decisions	NA	Cereal prices, rotation decisions, cereal supply	Estimated an optimal price for 50 percent set-aside option for cereal producer. Highlighted industry supply curve for different scenarios	FR
Santra et al. (2008)	To predict soil properties (field capacity and permanent wilting point) and prepare surface map at farm level	Ordinary kriging, semivariogram, Pedo transfer function	Bulk density, organic carbon, silt and clay content, field capacity, permanent wilting point,	Case study (Indian Agricultural Research Institute, New Delhi): Predicted surface maps were reasonably precise for farm level and regional-scale application	MT
Balendonck et al. (2009)	To develop irrigation management system for crop production with limited water availability and quality	Modelling, sensor systems, tensiometer, scheduling	Farm constraints, irrigation structures, crop types, water supplies, local goals	Explained the concept of flow-aid (6th framework European project) and progress of the first-year research	MT, FR
Molden et al. (2010)	To comprehensively analyse water productivity concept, identify approaches for its improvement and identify key constraints that must be overcome.	NA	NA	Improving water productivity will involve understanding of biophysical and socioeconomic environments at multiple scales. Highlighted priority areas were water productivity could be improved	EN
Yao and Yang (2010)	To evaluate soil salinity and its spatial distribution	Electromagnetic induction method for field survey, multiple linear regression models	Soil salinity	Case study (Lower yellow river delta) Spatial trend and semivariogram of field salinity status were illustrated.	MT
Dury et al. (2010)	To model the complexity of cropping plan decision making	Farmer's survey, abductive reasoning, modelling approach inspired from software development methods	Farm constraints that affect decisions, uncertainty and risk	Identified objects/concepts and dynamics that farmers use for crop planning. Individual farmer decision models were used to build generic cropping plan decision model.	FR
Belhouchette et al. (2011)	To assess the impact of nitrate directive on farming systems	Bio-economic modelling	Farm income, nitrate leaching, erosion and water consumption, irrigation, labour, soil, climate, crop rotation and crop management, 2003 CAP reform (baseline scenario)and Nitrate Directive (policy scenario)	Case study (Midi-Pyrenees region): Implementation of nitrate directive did not affect farm income. Nitrogen leaching did not change while water consumption and soil erosion increased and decreased respectively.	EN, FR
Lacroix and Thomas (2011)	To estimate the environmental impact of land and production decisions	Multivariate selection rules, panel data analysis	Profit, land and crop choices	Proposed procedure had advantages over Tobit procedure	MT, FR, EN
García-Vila and Fereres (2012)	To combine AquaCrop crop model and economic model to optimize irrigation at farm level	Optimization	Yield response to water, farm income, irrigation water constraints, variation in agricultural policies, product and water prices, variation in farmer communication of irrigation water allocation	Case study analysis (South-western Spain): Change in cropping pattern due to policies promoted water saving more than water price rise. Farm income was adversely affected by delay in water allocation.	MT, FR
González-Díaz et al. (2012)	To use crop rotation technique at landscape scale to control annual	Modelling		Crop rotation (crop sequence and crop allocation) with coordination among	FR, EN

(continued on next page)

Table 3 (*continued*)

Authors	Objective	Technique	Parameters/Indicators considered	Important Observations/ Implementation	Theme
	weeds in cereals using Avena sterilis as example		Weed population dynamics, seed dispersal fractions, management scenarios	farmers was suggested as an effective weed control strategy at landscape level	
Alexander and Moran (2013)	To explore impacts of perennial energy crops income variation on crop selection of risk averse farmers	Mathematical programming	Crop prices, crop yields, risk	Small acreage of energy crops in the UK were expected to be chosen for growing	FR
Dury et al. (2013)	To analyse farmer cropping plan decision making	Farmer's survey, methods of cognitive science	Irrigation, farmer's planning and reactive decisions in uncertainty	Farmers decision making process was continuous. Importance of putting farmland into spatial crop-management units was highlighted	FR
Bergez et al. (2014)	To capture crop model STICS in modelling platform RECORD	STICS, RECORD simulation modelling, MICMAC, AICHA, CRASH	Economic and epidemiological parameters, water shortage regulation, water table	Encapsulation of STICS and RECORD allows benefits from mutual exchange of data	FR, MT, EN
Galán-Martín et al. (2015)	To optimize cropping plan decisions under new common agricultural policy	Multi-stage linear programming	Greening rules in European Union's common agricultural policy	Case study of Spanish agricultural region: Proposed model maximizes net returns of farmers and could calculate minimum subsidy value for making greening rules economically appealing.	FR, MT
Buchholz et al. (2016)	To apply a business simulation game for ex-ante policy impact analysis of irrigation water policies at farm level	Business simulation game	Farmer behaviour towards water policy change, uncertain product prices and weather conditions	Case study of Germany farmers: water quota and water pricing schemes, both fundamentally exhibit equal effects of income while water quota is able to reduce irrigation application.	FR, MT
Scudiero et al. (2016)	Comparison of two techniques of mapping soil electrical conductivity	Analysis of Covariance (ANOCOVA), regression modelling, remote sensing	Salinity, canopy reflectance parameters, crop type, rainfall	Both techniques proved viable at large spatial scale, with ANOCOVA more appropriate for smaller resolution than remote sensing	MT, EN
Mekki et al. (2018)	To study impacts of farmland fragmentation on rain fed crop allocation in Mediterranean landscape	Farmer interviews, univariate and linear discriminant analysis	Field spatial distribution, crop types, land uses	Case study in Lebna watershed, Tunisia: Farmers implement collective rules of allocating crops when fields are isolated. Otherwise, allocation is based on crop sequence.	FR
De Pinto et al. (2019)	To examine the risk of climate change on farm land allocation and agricultural output in Zambia	Modelling – discrete choice model, mean variance utility function		Risk environment affects decision making. Aggregate effects of individual decisions should be assessed for economy-wide consequences. Risk mitigation strategies would improve nutritional status of low-income population	FR
Momm et al. (2019)	To quantify the effects of change in crop conversion and farming practices in upper sunflower river watershed	Modelling – Annualized agricultural non-point source watershed pollution model	Annual crop yield, irrigation, precipitation	High irrigation adoption indicated more short-term flow while crop conversion to corn/soybean indicated reduction in average annual sediment loads.	EN,MT
Etwire et al. (2019)	To model the factors that influence farmer's decision of crop selection in Ghana	Modelling - Structural Ricardian Model	Climate change scenarios	Extreme climate change would reduce revenue from maize and substitution with heat-tolerant millet	FR,MT
Corwin and Scudiero (2020)	To provide an overview of the characterization of soil variability using electrical conductivity at multiple scales	Characterization	Soil properties	Mobile electrical conductivity, protocols, guidelines, special considerations, data reliability tests, strengths and limitations are presented for characterization of soil property variation using electrical conductivity directed soil sampling	MT
Xiang et al. (2020)	To link DSSAT and MODFLOW to explore groundwater conservation strategies in irrigated areas	Simulation and Integrated modelling	Rate of irrigation, percolation, pumping rate and recharge rate	Case study of Ogallala aquifer in Kansas, USA: Predicted reduction in well capacities. Model could explore change in irrigation patterns, crop selection and climate change adoption	MT, EN
Sarker et al. (2020)	To explore potential of big data technologies for ensuring digital farming	SLR	Production at field level	Potential of big data in crop selection, yield prediction etc. Need for robust implementation strategies.	MT
Pahmeyer et al. (2021)	To develop decision support system for crop and manure fertilization	Optimization, big data analysis	field specific location factors such as labour endowments, field-to-farm distances and policy restrictions	German case study farm: Proposed strategies reduced losses in profit	FR, EN, MT

Notes:FR- Farmer's decision making; EN- Soil, water and agro-ecology; MT- Merits of innovative technologies and tools.

tries to maximize the output within limited resources. For instance, water unavailability is one of the primary constraints that hinders the prosperity of farming system and requires the farmer to optimize their irrigation. For irrigation decision, studies such as García-Vila and Fereres (2012) and Balendonck et al. (2009) may prove useful. García-Vila and Fereres (2012) designed strategies which included a combination of low and high-water consuming crops for water-restricted environments in southwestern region of Spain. With the use of certain hardware (sensors) systems, Balendonck et al. (2009) developed an irrigation management system for crop production under limited water with poor-quality

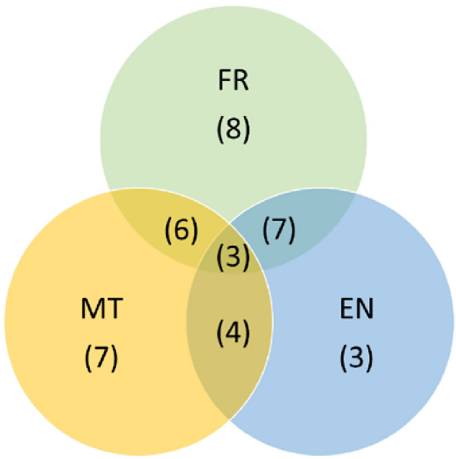

Fig. 5. Venn diagram depicting distribution of studies in themes. Notes: FR- Farmer's decision making; EN- Soil, water and agro-ecology; MT- Merits of innovative technologies and tools.

condition. A planning and management system for large irrigation scheme in the Alentejo region of Portugal was designed by Mira Da Silva et al. (2001).

3.2.1.2. Decision making process. Farmer's decisions are naturally influenced by farmer's attitude, behaviour, objectives and personality traits (Willock et al., 1999). Farming systems across the world have heterogonous characteristics therefore farmer's decision making is expected to be distinct and context specific. Dury et al. (2010) studied farmer's decision-making process, highlighted the complications and, proposed a framework for formalizing the stages in the decision-making process. An additional phenomenon that has recently challenged the decisions, judgements and predictions of the farmers is climate change which has increased uncertainty and risks. Thus, understanding farmer's decision-making process is crucial before designing effective adaption tools for farmers. Etwire et al. (2019) studied the factors that influence farmer's decision of crop selection in Ghana under scenarios of climate change. To contribute, De Pinto et al. (2019) showed how risk averting decisions could reinforce change in crop patterns driven by climate change impacts on precipitation and mean temperature. Changes in household dynamics and institutional reforms may cause farmer to adapt their cropping systems to changing circumstances. These adaptation decisions were studied by Wilson et al. (2003), Buchholz et al. (2016) and Mekki et al. (2018) wherein they focussed on changes in land fragmentation, water policy and cereal prices respectively. In short-listed literature, the approaches for understanding decision making process varied from econometrics to psychology. A cognitive approach was used by Dury et al. (2013) to understand the dynamics of cropping-plan decision-making in irrigated farm while Vavra and Colman (2003) deployed methods of economics to analyse farmer's behaviour of crop allocation. Farmer's decisions affect the regional agro-ecosystem and this phenomenon was studied by Lacroix and Thomas (2011) wherein they estimated the impacts of production decisions on environment.

3.2.2. Soil, water and agro-ecology

Relationship between cropping systems and the environment is crucial to understand the sustainability of the farm as well as regional agro-ecosystem. The properties of environmental elements such as soil, water, climate, flora, fauna etc. are important considerations during crop planning at farm level. Besides, interactions of crops with soil, water and fertigation have been a major area of study which has significantly contributed to scientific understanding of various agronomic processes and efficient crop planning (Keating and Thorburn, 2018). Models have been widely used to capture plant physiology, crop-soil process, crop-water process, yield predictions and more importantly interpret complex and variable performance of agronomic parameter for efficient crop planning. A study by Mohan and Jothiprakash (1998) from Tamil Nadu, India compare two established methods of estimating crop water requirements in a command area for crop planning. Since, farming systems use common-pool resources, their cropping plans determine the sustainability of the entire common-pool region and these choices affect the agro-ecology even at scales larger than farm or fields (Thenail et al., 2009). Lacroix and Thomas (2011) studied the impact of land and production decisions by farmer on environment and suggested policy recommendations to counter ill-effects on agro ecology. Similarly, study by Bergez et al. (2014) highlighted the lack of applicability of crop models for addressing environmental issues and therefore explored the possibility of integrating plant and soil processes developed in STICS with another modelling platform RECORD to widen the scope of STICS in addressing environmental issues like water shortage regulations, impacts of irrigation on water table, etc. Whereas González-Díaz et al. (2012) considered the population dynamics of weeds and simulated crop rotation scenarios to check if crop rotation could reduce growth of weeds at landscape level. Agriculture (especially open cultivation) is extremely dependent on climate and any unexpected variation like untimely rainfall, unusual temperature changes, cyclones etc. adversely affect the growth cycle of crops (Zilberman et al., 2004). Pitovranov (1988) explored the benefits of seasonal weather forecasts for crop scheduling and also studied the sensitivity of grain crop production with climate change.

Soil is an integral part of agro ecosystem, as it determines the ability of water and nutrient uptake and, acts as a medium for crop growth. Hence, a good knowledge of soil properties has always supported the farmer in crop planning. Scudiero et al. (2016) emphasized on the need for mapping the soil variability and developed innovative methods to map soil salinity in agronomical and environmentally relevant range. Other researchers have studied adaptation measures during institution changes for fertigation of soil. For example, Pahmeyer et al. (2021) developed a crop rotation based DSS for following 'greening rules' of the EU Common Agricultural Policy while minimizing the profit losses and Belhouchette et al. (2011) assessed the impact of nitrate directive at farm scale on farm income and environmental indicators. Similarly, Hasler (1998) analysed the environmental policy aimed at reducing nitrogen leaching at farm level and estimated its cost-effectiveness.

With global depletion and degradation of water resources, maintaining the quantity and quality of water resources at various scales has been the focus areas of researchers. Momm et al. (2019) studied how runoffs and sediment load in Mississippi River's alluvial floodplain, has been impacted due to recent crop conversions and changes in farm management practices. Molden et al. (2010) did a comprehensive analysis of water productivity concept and concluded that improvement in water productivity would involve understanding of biophysical and socioeconomic environments at multiple scales. Xiang et al. (2020) studied the impact of crop growth and crop yields on groundwater to manage aquifers sustainably. They linked an agronomic and a groundwater model and proposed that their system could be used for crop selection and climate change adaption. Planning water resource at basin or watershed level could involve complication because of poor water budgeting. Gap in understanding of water demands and productivity potential could lead to disparity in demand and supply of irrigation water. Mira Da Silva et al. (2001) designed a DSS for well-planned and managed water allocation in large irrigation scheme in Portugal.

3.2.3. Merits of innovative technologies and tools

Advancements in the field of analytics and engineering is evident in literature. With increasing scope in interdisciplinary research, many researchers across various disciplines have applied innovative methods/techniques in addressing crop planning problem. This theme includes studies which explicitly emphasize on effective tools/techniques/method to showcase their advantages and relevance in crop planning domain.

In the emerging field of big data science, Sarker et al. (2020) reviewed how big data could be used in digital farming. They highlighted huge potential in generating and analysing data as it would increase possibilities of scenario analysis which is a crucial element in farmer's decision-making. Pahmeyer et al. (2021) developed a DSS which used field specific big data with optimization modelling to derive crop rotation strategies. In other kind of study, Corwin and Scudiero (2020) compared remote sensing and near-ground measurements to map soil salinity at farm level for better decision making. They used regression modelling and analysis of covariance for processing remote sensing data and near-ground measurements respectively. For handling farm-level panel data, Lacroix and Thomas (2011) used multivariate selection rules to estimate the impacts of farmer's decision on environment. The problem statements of crop planning are often linked to resource scarcity and optimization technique provide best results in such cases (Singh, 2012). Optimization is a popular method in crop planning studies to derive maximum or minimum value of the desired objectives subjected to certain constraints (Rajni et al., 2018). Galán-Martín et al. (2015) applied multi-objective linear programming for optimizing cropping plan decisions under the new Common Agricultural Policy in Spain. García-Vila and Fereres (2012) used non-linear programming to develop a farm economic optimization model for irrigation management. Other than optimization, researchers have used different and unique techniques for analysing the farm level data to derive useful inference and decisions. Etwire et al. (2019) used Structural Ricardian method to analyse the decision data of Ghana farmers during climate change. Another work by Buchholz et al. (2016) designed a business game to collect and analyse farmers decision data regarding water policies. Mohan and Arumugam (1994) developed a rule based expert system that collected farm level data and suggested appropriate crops for cultivation. There are certain studies which showcased the use of already developed tools/algorithms such as crop models into their problem statements. For instance, a tool called as *Annualized Agricultural Non-Point Source* (AnnAGNPS) a watershed pollution model, developed by USDA was used by Momm et al. (2019) to simulate cropping scenarios and describe the sediment load in Mississippi River alluvial floodplain. Similarly, popular software *Decision* Support *System for Agrotechnology Transfer* (DSSAT), a crop simulation model, and MODFLOW for groundwater-flow simulation was used by Xiang et al. (2020) in their work to explore groundwater conservation techniques in irrigated areas. García-Vila and Fereres (2012) and Bergez et al. (2014) used AquaCrop and STICS crop model respectively wherein Bergez et al. (2014) used STICS in RECORD modelling platform to widen the scope of STICS in addressing environmental issues. Mohan and Jothiprakash (1998) compared FAO-Penman method and Duty-delta method for estimating crop water requirements. Certain studies have highlighted the hardware systems used for data collections. For example, Yao and Yang (2010) used mobile electromagnetic induction system (EM38 and EM31) and analysed the data obtained to study the spatial patterns of soil salinity whereas, Balendonck et al. (2009) worked on irrigation management system which used low-maintenance tensiometer, a wireless and low-power sensor network and an expert system for crop planning. In other kind of studies related to soil parameter measurement, Santra et al. (2008) studied spatial distribution of properties of soil using geostatistical tools such as original kriging and Semivariogram to generate surface map of hydraulic parameters. Corwin and Scudiero (2020) produced a methodological paper to give an overview of the soil electrical conductivity methods for characterising soil spatial variability.

4. Discussion

Crop planning has been a subject of research for several decades, and bibliometric analysis indicates its continuous growth in academia over the years. With growing uncertainties in farming systems across the world, crop planning problem has attracted researchers across various disciplines to study and develop sustainable cropping systems. The themes of studies in crop planning research have continuously evolved over time, indicating a synchronized progression in the field. Burst detection analysis demonstrated that crop planning research is being regularly updated and incorporated recent advancement in scientific tools and techniques.

The growing focus towards climate change and big data in crop planning research is justified by the growing challenges of climate variability (IPCC et al., 2023) and the better accessibility of agricultural data (USDA, 2024). This shift is promising, as it reflects researchers' efforts to tackle pressing issues while driving methodological advancements in the field.

The diverse themes of studies analysed in this review covered socio-economic factors and personal preferences that drive farmers' choices, understanding how environmental factors influence crop planning and, exploring the use of advanced tools and technologies to improve crop planning. Even though the reviewed literature covered many aspects of crop planning problem in terms of agronomy, ecology and economics, there was lack of consideration of small farming systems. This research gap is not trivial because the system boundaries and system components vary when the scale of system is changed (Ren et al., 2019).

4.1. Advancing research for small-scale farming systems

Research on crop planning for small farmers requires considering farm-household system, as household dominates the objectives of farming (McConnell et al., 1997). Their decisions are driven by household's needs and aspirations which are derived by broad social-value structures and local traditions. Small farms operate in semi-subsistence or part-commercial environments and are flexible in their approach, which means they could change their cropping plan for next season if their cultivation strategy changes (Chambers and Ghildyal, 1985). In such a case, designing an optimal cropping plan (as the majority of the optimization studies in this field do) ignores their flexibility of decisions and choices while reducing farmer's empowerment, hence making it an impractical design. A few authors have, however, generated alternative solutions using analytical tools (for example: pareto optimal frontier) or field conditions (scheduling) and compared them based on multiple criteria to obtain an optimal solution (Dury et al., 2012). However, none have considered a factorial design for crop mixes while generating alternatives. Factorial design is important for crop planning, especially when the agro ecology supports many options for cultivation. Factorial design is also useful when crop diversification and profitability are desirable. Since crop diversification requires expanding the portfolio to multiple crops by choosing among favourable options, factorial design enables exploring all possibilities of crop mix to capture the full potential of cultivation.

Small farmers prefer crop diversity, which increases their market opportunities, household food security, and adaptability to climate change (Bellon et al., 2020). Crop diversification is a well-studied concept in the literature. Several studies have estimated the economic, social and environmental impact of crop diversification as reported by Rahman (2009). Similarly, various indices have been developed to quantify the extent or intensity of crop diversification such as Herfindahl index, simpson's index, ogive index, entropy index, modified entropy index, composite entropy index (De and Chattopadhyay, 2010). To design a cropping plan with crop diversity, it is important to calculate the diversity index to measure how each crop contributes in the overall production of the farming system. The diversity index suggests the stability of the cropping plan in which a higher value would mean low risk as there is diversity in production, while a lower value would mean high risk due to concentration in production (McConnell et al., 1997). However, diversity index has been rarely estimated during production planning in the existing literature.

Many crops, such as onion, radish, potato etc. have a single harvest while crops like ladyfinger, brinjal, cluster beans etc. have dispersed harvest. This introduces the concept of time-dispersion of yields in crop planning. The preference of time dispersion depends on the types of farmers. For example, small farmers in India generally prefer income dispersed throughout their cultivation season as continuous income to manage their personal expenses (Dev, 2012) while large farmers target concentrated production and income for bulk production and export (McConnell et al., 1997). The study of time dispersion is substantial for post-harvest management of perishable agricultural produce (Ahumada and Villalobos, 2011) like vegetables. This issue has been addressed by sowing or harvesting schedule modelling (Ali et al., 2009). However, no study has estimated the intensity of production or income distribution along the cultivation period. It is important to quantify the time dispersion of production or income especially for small farmers because: a) they are subsistence-based b) they lack appropriate storage facilities c) they try to minimize family debts. Therefore, while designing cropping plans for small farmers, a high level of time dispersion is desirable (McConnell et al., 1997).

The role of data and models in crop planning domain should be beyond research purposes and directly benefit the primary stakeholders, i.e., the farmers. Agricultural researchers also need a focus on model/framework dissemination and implementation, otherwise, their work is merely a contribution to the scientific literature. Lately, software industry and agricultural modelling community has seen collaborations due to which many models have been upgraded from prototype to dissemination stage (Holzworth et al., 2015). The rate at which digitization and communication technologies have been growing suggests an unrealised potential for crop planning data and models to be effectively developed and utilized. There are successful examples such as DSSAT (Jones et al., 2003) and APSIM (Keating et al., 2003) which have developed software platforms for wide scale dissemination and coverage. There is a need and demand for taking the scientific research from labs to farms and use of ICT in crop planning research could be a promising future direction.

4.2. Limitation and future directions

The current study is first of a kind review of crop planning literature however despite reasonable knowledge generated by this study, some limitations of this research need to be acknowledged. Basically, this study used a language filter and only publication in English were included. Also, generalisation of particular keywords would have omitted relevant studies during literature search. Besides, crop planning is a specific component of larger farm management process, but we avoided keywords such as "farm management" or "farm planning" in our literature search because it diverted our focus and included studies pertaining to several aspects other than crop planning (like livestock management, farm operations, farm infrastructure etc). Therefore, we looked at crop planning problem in isolation to achieve our research objectives. Based on these limitations, a holistic and deeper content analysis is suggested for further research when reviewing crop planning problem.

Future research in crop planning should focus on creating flexible frameworks that's compatible for small farming systems and empower farmers to adapt cropping plans dynamically. Incorporating factorial design, diversity indices, time dispersion, climate vulnerability, resource-use efficiency in crop mix planning are potential directions for future studies. Additionally, researchers should aspire to develop pathways that address crop planning problem in the context of challenges posed by changing agricultural, environmental and socio-economic landscapes.

5. Conclusion

This study was intended to understand the main characteristics of crop planning literature and answer how crop planning problem has been addressed at farm level. The bibliometric analysis identified key research hotspots such as optimization, irrigation, sustainability and adaptation, with a notable shift towards pressing issues such as climate change, water resource management and upcoming analytical fields such as big data. Besides this quantitative analysis, a qualitative review of select literature was done which suggested the interdisciplinary nature of the crop planning problem. The qualitative review revealed a gap in literature, particularly in the context of small farming systems, which have been largely overlooked. Several recommendations were highlighted in this study when crop planning problem is being studied for small scale farming systems. Recommendations were factorial design for crop combinations, choices in options, estimation of crop diversity index and relative time-dispersion in yields and upgradation of models from prototype to dissemination stage using software industry and ICT. These recommendations, along with the emerging research topics in crop planning, could serve as potential directions, fostering increased interest in the field and unlocking its unexplored potential.

CRediT authorship contribution statement

Aniket Deo: Writing – review & editing, Writing – original draft, Visualization, Software, Resources, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Namita Sawant:** Writing – review & editing, Visualization, Resources, Conceptualization. **Amit Arora:** Conceptualization, Supervision. **Subhankar Karmakar:** Conceptualization, Supervision.

Declaration of interest

None.

Acknowledgements

We would like to sincerely thank the Editors and the anonymous Referees for considering and providing their insightful comments and constructive suggestions to improve the quality of the manuscript. We acknowledge the Ph.D. fellowship provided to the first author by the Ministry of Education, Government of India.

References

Ahumada, O., Villalobos, J.R., 2011. Operational model for planning the harvest and distribution of perishable agricultural products. Int. J. Prod. Econ. 133 (2), 677–687. https://doi.org/10.1016/j.ijpe.2011.05.015.

Alexander, P., Moran, D., 2013. Impact of perennial energy crops income variability on the crop selection of risk averse farmers. Energy Pol. 52, 587–596. https://doi.org/10.1016/j.enpol.2012.10.019.

Ali, O., Verlinden, B., Van Oudheusden, D., 2009. Infield logistics planning for crop-harvesting operations. Eng. Optim. 41 (2), 183–197. https://doi.org/10.1080/03052150802406540.

Araújo, C.A., 2006. Bibliometrics: historical evolution and current issues. question 12 (1), 11–32.

Balendonck, J., Stanghellini, C., Hemming, J., Kempkes, F.L.K., Van Tuijl, B.A.J., 2009. Farm level optimal water management: assistant for irrigation under deficit (flow-aid). Acta Hortic. 807, 247–254. https://doi.org/10.17660/actahortic.2009.807.32.

Belhouchette, H., Louhichi, K., Therond, O., Mouratiadou, I., Wery, J., Ittersum, M.V., Flichman, G., 2011. Assessing the impact of the Nitrate Directive on farming systems using a bio-economic modelling Chain. Agric. Syst. 104 (2), 135–145. https://doi.org/10.1016/j.agsy.2010.09.003.

Bellon, M.R., Kotu, B.H., Azzarri, C., Caracciolo, F., 2020. To diversify or not to diversify, that is the question. Pursuing agricultural development for smallholder farmers in marginal areas of Ghana. World Dev. 125, 104682. https://doi.org/10.1016/j.worlddev.2019.104682.

Bergez, J.E., Raynal, H., Launay, M., Beaudoin, N., Casellas, E., Caubel, J., Chabrier, P., Coucheney, E., Dury, J., Garcia de Cortazar-Atauri, I., Justes, E., Mary, B., Ripoche, D., Ruget, F., 2014. Evolution of the STICS crop model to tackle new environmental issues: new formalisms and integration in the modelling and simulation platform RECORD. Environ. Model. Software 62, 370–384. https://doi.org/10.1016/j.envsoft.2014.07.010.

Buchholz, M., Holst, G., Musshoff, O., 2016. Irrigation water policy analysis using a business simulation game. Water Resour. Res. 52, 7980–7998. https://doi.org/10.1002/2016WR018857.

Chambers, R., Ghildyal, B.P., 1985. Agricultural research for resource-poor farmers: the farmer-first-and-last model. Agric. Adm. 20, 1–30. https://doi.org/10.1016/0309-586X(85)90063-9.

Chand, R., 2017. Presidential address: doubling farmers' income: strategy and prospects. Indian J. Agric. Econ. 71. https://ageconsearch.umn.edu/record/302243/files/06-Presidential%20Address-Ramesh%20chand.pdf. (Accessed 17 January 2025).

Chen, C., 2006. CiteSpace II: detecting and visualizing emerging trends and transient patterns in scientific literature. J. Am. Soc. Inf. Sci. Technol. 57, 359–377. https://doi.org/10.1002/asi.20317.
Corwin, D.L., Scudiero, E., 2020. Field-scale apparent soil electrical conductivity. Soil Sci. Soc. Am. J. 84 (5), 1405–1441. https://doi.org/10.1002/saj2.20153.
De Pinto, A., Smith, V.H., Robertson, R.D., 2019. The role of risk in the context of climate change, land use choices and crop production: evidence from Zambia. Clim. Res. 79 (1), 39–53. https://doi.org/10.3354/cr01581.
De, U.K., Chattopadhyay, M., 2010. Crop diversification by poor peasants and role of infrastructure: evidence from West Bengal. J. Dev. Agric. Econ. 2 (10), 340–350.
Dev, M.S., 2012. Small Farmers in India: Challenges and Opportunities. Indira Gandhi Institute of Development, Research, Mumbai. http://oii.igidr.ac.in:8080/jspui/bitstream/2275/262/1/WP-2012-014.pdf. (Accessed 17 January 2025).
Dury, J., Garcia, F., Reynaud, A., Bergez, J.-E., 2013. Cropping-plan decision-making on irrigated crop farms: a spatio-temporal analysis. Eur. J. Agron. 50, 1–10. https://doi.org/10.1016/j.eja.2013.04.008.
Dury, J., Garcia, F., Reynaud, Arnaud, Thérond, O., Bergez, Jacques-Eric, 2010. Modelling the complexity of the cropping plan decision-making. Int. Congres Environ. Model. Software 257, 569–576. https://scholarsarchive.byu.edu/iemssconference/2010/all/257.
Dury, J., Schaller, N., Garcia, F., Reynaud, A., Bergez, J.E., 2012. Models to support cropping plan and crop rotation decisions. A review. Agron. Sustain. Dev. 32, 567–580. https://doi.org/10.1007/s13593-011-0037-x.
Ellegaard, O., Wallin, J.A., 2015. The bibliometric analysis of scholarly production: how great is the impact? Scientometrics 105, 1809–1831. https://doi.org/10.1007/s11192-015-1645-z.
Etwire, P.M., Fielding, D., Kahui, V., 2019. Climate change, crop selection and agricultural revenue in Ghana: a structural ricardian analysis. J. Agric. Econ. 70 (2), 488–506. https://doi.org/10.1111/1477-9552.12307.
Forster, D.L., 2002. Effects of conservation tillage on the performance of Lake Erie basin farms. J. Environ. Qual. 31 (1), 32–37. https://doi.org/10.2134/jeq2002.3200.
Galán-Martín, Á., Pozo, C., Guillén-Gosálbez, G., Vallejo, A.A., Esteller, L.J., 2015. Multi-stage linear programming model for optimizing cropping plan decisions under the new Common Agricultural Policy. Land Use Pol. 48, 515–524. https://doi.org/10.1016/j.landusepol.2015.06.022.
García-Vila, M., Fereres, E., 2012. Combining the simulation crop model AquaCrop with an economic model for the optimization of irrigation management at farm level. Eur. J. Agron. 36 (1), 21–31. https://doi.org/10.1016/j.eja.2011.08.003.
Gomaa, W., Harraz, N., el Tawil, A., 2011. Crop planning and water management: a survey. In: Proceedings of the 41st International Conference on Computers & Industrial Engineering, pp. 319–324. Los Angeles, CA.
González-Díaz, L., Van Den Berg, F., Van Den Bosch, F., González-Andújar, J.L., 2012. Controlling annual weeds in cereals by deploying crop rotation at the landscape scale: avena sterilis as an example. Ecol. Appl. 22 (3), 982–992. https://doi.org/10.1890/11-1079.1.
Harden, A., Thomas, J., 2010. Mixed Methods and Systematic Reviews: Examples and Emerging Issues. Sage Handbook of Mixed Methods in Social & Behavioral Research 2. Sage Publications, pp. 749–774.
Hasler, B., 1998. Analysis of environmental policy measures aimed at reducing nitrogen leaching at the farm level. In: Proceedings of the First Internation Nitrogen Conference, pp. 749–754. https://doi.org/10.1016/B978-0-08-043201-4.50106-4.
Holzworth, D.P., Snow, V., Janssen, S., Athanasiadis, I.N., Donatelli, M., Hoogenboom, G., White, J.W., Thorburn, P., 2015. Agricultural production systems modelling and software: current status and future prospects. Environ. Model. Software 72, 276–286. https://doi.org/10.1016/j.envsoft.2014.12.013.
IPCC, 2023. Summary for policymakers. In: Lee, H., Romero, J. (Eds.), Climate Change 2023: Synthesis Report. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team. IPCC, Geneva, Switzerland, pp. 1–34. https://mural.maynoothuniversity.ie/id/eprint/17886. (Accessed 17 January 2025).
Itoh, T., Ishii, H., Nanseki, T., 2003. A model of crop planning under uncertainty in agricultural management. Int. J. Prod. Econ. 81, 555–558. https://doi.org/10.1016/S0925-5273(02)00283-9.
Jones, J.W., Hoogenboom, G., Porter, C.H., Boote, K.J., Batchelor, W.D., Hunt, L.A., Wilkens, P.W., Singh, U., Gijsman, A.J., Ritchie, J.T., 2003. The DSSAT cropping system model. Eur. J. Agron. 18, 235–265. https://doi.org/10.1016/S1161-0301(02)00107-7.
Jones, J.W., Thornton, P.K., Hansen, J.W., 1997. Opportunities for systems approaches at the farm scale. In: Teng, P.S., Kropff, M.J., ten Berge, H.F.M., Dent, J.B., Lansigan, F.P., van Laar, H.H. (Eds.), Applications of Systems Approaches at the Farm and Regional Levels Volume 1, Systems Approaches for Sustainable Agricultural Development, vol. 5. Springer, Dordrecht. https://doi.org/10.1007/978-94-011-5416-1_1.
Kamilaris, A., Kartakoullis, A., Prenafeta-Boldú, F.X., 2017. A review on the practice of big data analysis in agriculture. Comput. Electron. Agric. 143, 23–37. https://doi.org/10.1016/j.compag.2017.09.037.
Keating, B.A., Carberry, P.S., Hammer, G.L., Probert, M.E., Robertson, M.J., Holzworth, D., Huth, N.I., Hargreaves, J.N.G., Meinke, H., Hochman, Z., 2003. An overview of APSIM, a model designed for farming systems simulation. Eur. J. Agron. 18, 267–288. https://doi.org/10.1016/S1161-0301(02)00108-9.
Keating, B.A., Thorburn, P.J., 2018. Modelling crops and cropping systems—evolving purpose, practice and prospects. Eur. J. Agron. 100, 163–176. https://doi.org/10.1016/j.eja.2018.04.007.
Lacroix, A., Thomas, A., 2011. Estimating the environmental impact of land and production decisions with multivariate selection rules and panel data. Am. J. Agric. Econ. 93 (3), 784–802. https://doi.org/10.1093/ajae/aar008.
Lowder, S.K., Skoet, J., Raney, T., 2016. The number, size, and distribution of farms, smallholder farms, and family farms worldwide. World Dev. 87, 16–29. https://doi.org/10.1016/j.worlddev.2015.10.041.
McConnell, D.J., MacConnell, D.J., Dillon, J.L., 1997. Farm management for Asia: a systems approach. In: FAO Farm Systems Management Series. FAO, Rome.
McCown, R.L., 2002. Changing systems for supporting farmers' decisions: problems, paradigms, and prospects. Agric. Syst. 74 (1), 179–220. https://doi.org/10.1016/S0308-521X(02)00026-4.
Mekki, I., Bailly, J.S., Jacob, F., Chebbi, H., Ajmi, T., Blanca, Y., Zairi, A., Biarnès, A., 2018. Impact of farmland fragmentation on rainfed crop allocation in Mediterranean landscapes: a case study of the Lebna watershed in Cap Bon, Tunisia. Land Use Pol. 75, 772–783. https://doi.org/10.1016/j.landusepol.2018.04.004.
Mira Da Silva, L., Park, J.R., Keatinge, J.D.H., Pinto, P.A., 2001. A decision support system to improve planning and management in large irrigation schemes. Agric. Water Manag. 51 (3), 187–201. https://doi.org/10.1016/S0378-3774(01)00124-X.
Mohan, S., Arumugam, N., 1994. CROPES: a rule-based expert system for crop selection in India. Trans. ASAE (Am. Soc. Agric. Eng.) 37 (4), 1355–1363. https://doi.org/10.13031/2013.28218.
Mohan, S., Jothiprakash, V., 1998. Crop water requirements in a command area - a comparative analysis. J. Inst. Eng. India Civ. Eng. Div. 79, 73–77.
Molden, D., Oweis, T., Steduto, P., Bindraban, P., Hanjra, M.A., Kijne, J., 2010. Improving agricultural water productivity: between optimism and caution. Agric. Water Manag. 97 (4), 528–535. https://doi.org/10.1016/j.agwat.2009.03.023.
Momm, H.G., Porter, W.S., Yasarer, L.M., ElKadiri, R., Bingner, R.L., Aber, J.W., 2019. Crop conversion impacts on runoff and sediment loads in the Upper Sunflower River watershed. Agric. Water Manag. 217, 399–412. https://doi.org/10.1016/j.agwat.2019.03.012.
Mongeon, P., Paul-Hus, A., 2016. The journal coverage of Web of Science and Scopus: a comparative analysis. Scientometrics 106, 213–228. https://doi.org/10.1007/s11192-015-1765-5.
Nevo, A., Oad, R., Podmore, T.H., 1994. An integrated expert system for optimal crop planning. Agric. Syst. 45 (1), 73–92. https://doi.org/10.1016/S0308-521X(94)90281-X.
Oraee, M., Hosseini, M.R., Papadonikolaki, E., Palliyaguru, R., Arashpour, M., 2017. Collaboration in BIM-based construction networks: a bibliometric-qualitative literature review. Int. J. Proj. Manag. 35 (7), 1288–1301. https://doi.org/10.1016/j.ijproman.2017.07.001.
Pahmeyer, C., Kuhn, T., Britz, W., 2021. 'Fruchtfolge': a crop rotation decision support system for optimizing cropping choices with big data and spatially explicit modelling. Comput. Electron. Agric. 181. https://doi.org/10.1016/j.compag.2020.105948.
Petticrew, M., Roberts, H., 2008. Systematic Reviews in the Social Sciences: A Practical Guide. Blackwell Publishing. https://doi.org/10.1002/9780470754887.
Pitovranov, S.E., 1988. The effects of climatic variations on agriculture in the semi-arid zone of the European USSR: B. The Saratov region. In: Parry, M.L. (Ed.), The Impact of Climatic Variations on Agriculture, vol. 2. Kluwer, pp. 629–664.
Pruntseva, G., Popadynets, N., Barna, M., Stetsiv, I., Yakubiv, V., Shymanovska-Dianych, L., Fedotova, Y., Karpiak, M., Hryhoruk, I., 2021. The impact of governance on agricultural production as an exclusive factor of the country's food security. Accounting 7 (1), 75–80. https://doi.org/10.5267/j.ac.2020.10.012.
Rahman, S., 2009. Whether crop diversification is a desired strategy for agricultural growth in Bangladesh? Food Pol. 34 (4), 340–349. https://doi.org/10.1016/j.foodpol.2009.02.004.
Rajni, J., Malangmeih, L., Raju, S.S., Srivastava, S.K., Kingsly, I., Kaur, A.P., 2018. Optimization techniques for crop planning: a review. Indian J. Agric. Sci. 88, 1826–1835. https://doi.org/10.56093/ijas.v88i12.85423.
Ren, C., Liu, S., van Grinsven, H., Reis, S., Jin, S., Liu, H., Gu, B., 2019. The impact of farm size on agricultural sustainability. J. Clean. Prod. 220, 357–367. https://doi.org/10.1016/j.jclepro.2019.02.151.
Rodrigues, S.P., Van Eck, N.J., Waltman, L., Jansen, F.W., 2014. Mapping patient safety: a large-scale literature review using bibliometric visualisation techniques. BMJ Open 4 (3). https://doi.org/10.1136/bmjopen-2013-004468.
Sands, R., Meade, B., Seale Jr, J.L., Robinson, S., Seeger, R., 2023. Scenarios of Global Food Consumption: Implications for Agriculture (Report No. ERR-323). U.S. Department of Agriculture, Economic Research Service. https://ageconsearch.umn.edu/record/338943/?v=pdf. (Accessed 17 January 2025).
Santra, P., Chopra, U.K., Chakraborty, D., 2008. Spatial variability of soil properties and its application in predicting surface map of hydraulic parameters in an agricultural farm. Curr. Sci. 95 (7), 937–945. http://www.jstor.org/stable/24103193.
Sarker, M.N.I., Islam, M.S., Murmu, H., Rozario, E., 2020. Role of big data on digital farming. Int. J. Sci. Technol. Res. 9 (4), 1222–1225.
Scudiero, E., Skaggs, T.H., Corwin, D.L., 2016. Comparative regional-scale soil salinity assessment with near-ground apparent electrical conductivity and remote sensing canopy reflectance. Ecol. Indicat. 70, 276–284. https://doi.org/10.1016/j.ecolind.2016.06.015.
Singh, A., 2012. An overview of the optimization modelling applications. J. Hydrol. 466, 167–182. https://doi.org/10.1016/j.jhydrol.2012.08.004.
Thenail, C., Joannon, A., Capitaine, M., Souchère, V., Mignolet, C., Schermann, N., Di Pietro, F., Pons, Y., Gaucherel, C., Viaud, V., 2009. The contribution of crop-rotation organization in farms to crop-mosaic patterning at local landscape scales. Agric. Ecosyst. Environ. 131 (3–4), 207–219. https://doi.org/10.1016/j.agee.2009.01.015.
USDA, 2024. National Agricultural Statistics Service - Data and Statistics. https://www.nass.usda.gov/Data_and_Statistics/. (Accessed 17 January 2025).
Van Eck, N.J., Waltman, L., 2010. Software survey: VOSviewer, a computer program for bibliometric mapping. Scientometrics 84 (2), 523–538. https://doi.org/10.1007/s11192-009-0146-3.

Vavra, P., Colman, D., 2003. The analysis of UK crop allocation at the farm level: implications for supply response analysis. Agric. Syst. 76 (2), 697–713. https://doi.org/10.1016/S0308-521X(02)00075-6.

Willock, J., Deary, I.J., McGregor, M.M., Sutherland, A., Edwards-Jones, G., Morgan, O., Dent, B., Grieve, R., Gibson, G., Austin, E., 1999. Farmers' attitudes, objectives, behaviors, and personality traits: the Edinburgh study of decision making on farms. J. Vocat. Behav. 54 (1), 5–36. https://doi.org/10.1006/jvbe.1998.1642.

Wilson, P., Gibbons, J., Ramsden, S., 2003. The impact of cereal prices and policy on crop rotations and supply response. J. Agric. Econ. 54 (2), 313–323. https://doi.org/10.1111/j.1477-9552.2003.tb00065.x.

Xiang, Z., Bailey, R.T., Nozari, S., Husain, Z., Kisekka, I., Sharda, V., Gowda, P., 2020. DSSAT-MODFLOW: a new modeling framework for exploring groundwater conservation strategies in irrigated areas. Agric. Water Manag. 232. https://doi.org/10.1016/j.agwat.2020.106033.

Yao, R., Yang, J., 2010. Quantitative evaluation of soil salinity and its spatial distribution using electromagnetic induction method. Agric. Water Manag. 97 (12), 1961–1970. https://doi.org/10.1016/j.agwat.2010.02.001.

Zilberman, D., Liu, X., Roland-Holst, D., Sunding, D., 2004. The economics of climate change in agriculture. Mitig. Adapt. Strateg. For. Glob. Change 9, 365–382. https://doi.org/10.1023/B:MITI.0000038844.72226.13.